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Forest Succession in Western Montana— a Computer Model Designed for Resource Managers

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ABSTRACT

A quantitative computer model of succession (FORSUM) has been developed for use by land managers in predicting response of forest vegetation to silvicultural treatments and wildfire. FORSUM allows evaluation of the effects of alternative treatments. The model predicts temporal changes in canopy cover for major species in four habitat types common to western Montana. Species establishment is based on regenerative strategies; then subsequent changes in cover for each species are modeled using regression equations. FORSUM also contains an easy-to-use, interactive data input routine with error checking capability and two skill levels. Output is offered in both tabular and graphic format. In a validation of FORSUM, species cover was predicted accurately 74 percent of the time. Accuracy ranged from 69 percent to 78 percent. The computer code consists of 21 subroutines and was written in FORTRAN 77. It can be modified to incorporate additional habitat types with minimal effort.

KEYWORDS: pathway model, regression, interactive program, vegetal response, succession

Predicting the composition of plant communities that arise after different silvicultural treatments or wildfire plays an important role in forest management. Because successional community composition is strongly influenced by the composition of the predisturbance vegetation and by type and intensity of disturbance, managers can manipulate successional trends to meet management objectives by selecting different silvicultural treatments (Arno and others 1985). But choosing the best treatment to meet management objectives can sometimes be difficult because

there are few quantitative methods available to predict postdisturbance plant coverages. Successional classification systems such as Arno and others (1985) and Steele (1984) relate successional trends to wildfire and site treatment but yield only qualitative predictions. To overcome this problem, a study was conducted to quantify coverage response to various disturbances and then develop a computer model for predicting succession in four habitat types commonly found in west-central Montana. This model, called FORSUM (a **FOR**est **SU**ccession **M**odel), is currently available for use by land managers. The purpose of this paper is to describe the assumptions and operations of FORSUM as well as present an evaluation of the accuracy of the model.

FORSUM is based on the classification system of Arno and others (1985). In this classification system, site characteristics, predisturbance plant composition, and type and severity of treatment define major successional pathways within a habitat type phase. Plant species establishment after a disturbance is based on regenerative strategies. Subsequent growth in cover is projected using regression equations. FORSUM predicts plant coverage for 74 species of trees, shrubs, and herbs. The model is based on an analysis of 774 actual stands, including some paired treated and untreated stands. Because all data were collected within the study area defined in figure 1, it is strongly recommended that use of FORSUM not be extrapolated to areas outside these boundaries.

The model predicts succession for seven phases in the following Montana habitat types (Pfister and others 1977):

1. *Pseudotsuga menziesii*
Physocarpus malvaceus (PSME/PHMA)
2. *Pseudotsuga menziesii*
Vaccinium globulare (PSME/VAGL)
3. *Abies lasiocarpa*/*Xerophyllum tenax* (ABLA/XETE)
4. *Abies lasiocarpa*/*Menziesia ferruginea* (ABLA/MEFE)

These habitat types comprise more than half the forested landscape in west-central Montana. There are four treatment types represented in the model: (1) stand-replacing

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wildfire, (2) clearcut and broadcast burn, (3) clearcut and mechanical scarification, (4) clearcut with no site treatment. In addition, three severity levels are used for mechanical scarification and broadcast burn treatments and two severity levels (moderate and high) are used for wildfires. Table 1 presents the severity levels and details the criteria used to assess the severity type for a disturbed stand.

METHODS

The data base used for model construction was created by pooling data collected by Arno and others (1985) for the classification study, with data collected for a subsequent evaluation of the classification (Keane 1984). These data sets are from the Lolo and Bitterroot National Forests, the southern half of the Flathead National Forest,

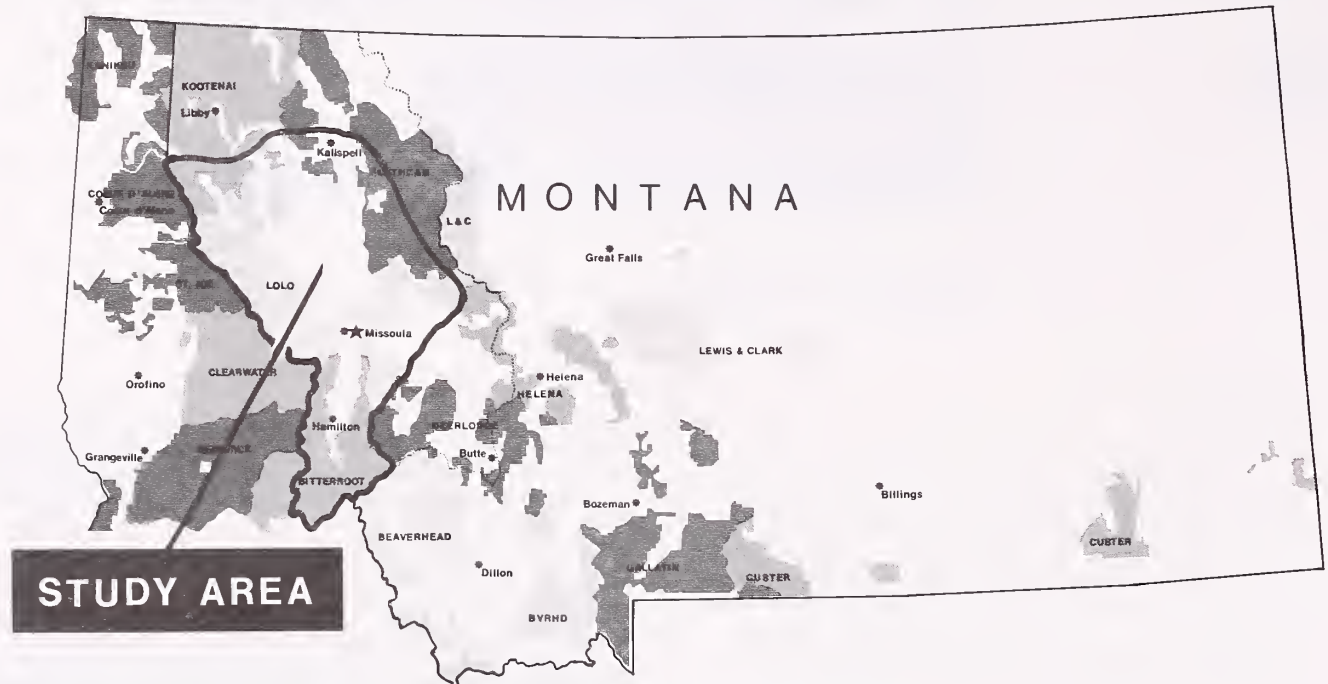


Figure 1—Area where the data were collected for model construction, and where FORSUM can be applied.

Table 1—Guidelines used in the determination of treatment severity. Wildfire or broadcast burn guidelines are partially taken from Ryan and Noste (1983)

Severity type	Treatment types	
	Wildfire or broadcast burn	Mechanical scarification
Low or light	Most fine fuels burned; unevenly distributed burn mosaic with some spots unburned; fresh stumps barely charred; woody plants scorched but not consumed; large woody fuels remain unburned; regeneration mostly residual.	5-25 percent of area scarified; most woody plants intact; most stumps untouched; regeneration mostly residual.
Moderate or medium	Nearly all fine fuels consumed with some of the larger woody fuel partially consumed; small areas of exposed mineral soil; some woody plants consumed; uneven or patchy distribution of fire intensity; fresh stumps charred mostly on sides.	20-40 percent of the area scarified; woody shrubs ripped up; areas of exposed mineral soil frequent but unevenly distributed.
High or heavy	Many areas of exposed mineral soil; many shrubs wholly or partially consumed; some stumps partially consumed and most are charred on top; many large woody fuels consumed; fire intensity is mostly evenly distributed.	40-100 percent of area scarified; many shrubs displaced; large areas of bare mineral soil; residual regeneration rare; many stumps and grass tussocks uprooted; evidence of some soil erosion (rill and gully).

and parts of the Flathead Indian Reservation (fig. 1). A single, circular, 375-m² macroplot was used to characterize the vegetation in each sample stand (Arno and others 1985). Canopy coverages for all woody and herbaceous species in the macroplot were ocularly estimated using the canopy cover classes shown in table 2 (Pfister and others 1977). Tree canopy coverage was estimated for each of three structural classes: "saplings" (<4 inches d.b.h.), "poles" (4 to 12 inches d.b.h.), and "mature trees" (>12 inches d.b.h.). Other important site and stand variables recorded include elevation, aspect, slope, stand age, type, and general severity of treatment, average d.b.h. of domi-

nant trees in the stand, and stand basal area. Data from many adjacent treated and untreated stands on the same sites were taken to allow interpretations of treatment response, with minimal site-related differences.

The first step in constructing FORSUM was inspecting the sampled data to select the most frequently occurring plant species in each habitat type for modeling. Then the selected species were subjectively categorized into ecological groups based on their method of establishment, relative shade tolerance, and life form (Keane 1985a). These ecological groups were used as guidelines for the establishment of a species after various simulated perturbations. For example, since *Ceanothus velutinus* produces seeds that can remain viable in the soil for many decades, it was placed in the ecological group Soil Seed Bank Plants. The guidelines for establishment of plants in this group are (1) seeds can only germinate after a moderate-to high-severity fire; (2) the plant need not be visible on the predisturbance site, but it must be present in nearby stands of similar environmental characteristics; and (3) the perturbation must remove the forest overstory. These guidelines were programmed into a subroutine for inclusion in the final FORSUM program.

Next, the data were stratified by successional pathway (example shown in fig. 2). Each pathway is a consequence of type and severity of disturbance and predisturbance composition. A multiple regression analysis was then performed on the data in each pathway. Variables were

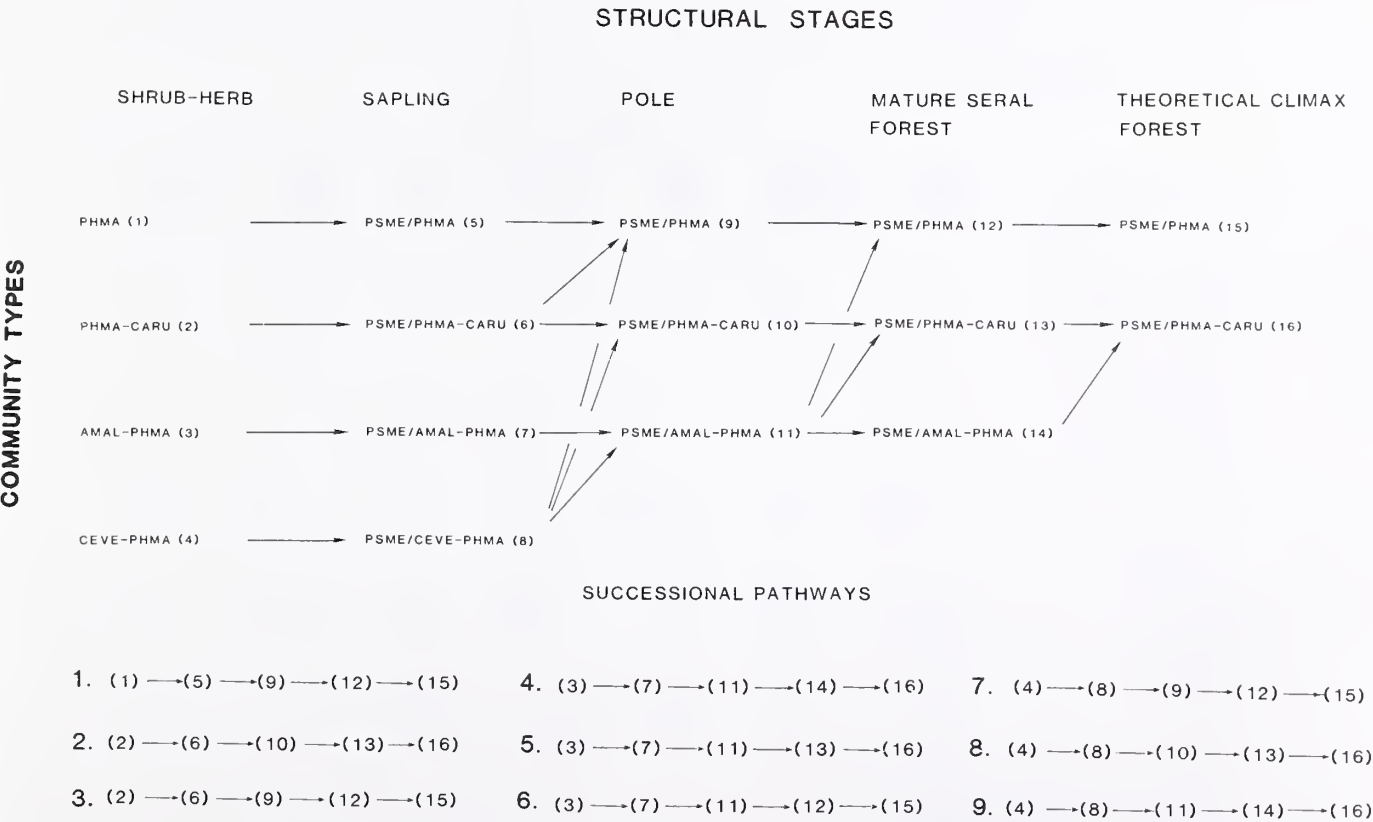


Figure 2—Successional pathways recognized in the PSME/PHMA,DRY habitat type phase. These pathways were the most common and contained adequate data for regression analysis. Numbers next to community name denote community number. Successional pathways (below) are designated by sequences of community type numbers.

chosen for inclusion in regression analysis based on interpretations of many graphs and scattergrams. The Stepwise Regression method (SPSS 1983) was then used to produce final regression equations for each pathway from each set of selected variables. These equations predict species canopy coverage from site, type and severity of treatment, vegetational variables, and various transformations of all these variables. Each species has a unique regression equation for each successional pathway. All regression coefficients and equation forms were stored in computer data files for access by the main computer program.

Once regression analysis was completed, the model was then programmed in FORTRAN 77 computer language, using regression equations as the foundation of the program. To compensate for programming and data limitations, certain assumptions had to be made:

1. The successional pathways defined by Arno and others (1985) accurately represent forest succession for these habitat type phases.
2. In any individual pathway or treatment, each plant species has only one main method of establishment or expansion; all other methods are assumed to be insignificant. But a species might have more than one method of expansion across treatments, pathways, and habitat type phases.
3. Vegetatively reproducing plants are only present in the postdisturbance community if they were present in the predisturbance community. Thus reproduction from seed for these types of plants is considered minimal.

4. There is always a seed source for all modeled trees in a habitat type phase.

After FORSUM was programmed, an additional 29 paired (treated and untreated) sites were sampled throughout the study area for a test of the model. More than one treated stand was sometimes sampled on a site. Although not every pathway could be tested with only 29 sample sites, this "validation" does provide a measure of model accuracy. In this "validation" procedure, data from the untreated (mature) stands were used as inputs to FORSUM. The type and intensity of treatment were then specified, generating predictions of posttreatment plant coverages. These predictions were compared to the actual cover data collected for treated (disturbance) stands. Percent accuracy was determined by dividing number of correct cover predictions by the total number of predictions.

RESULTS AND DISCUSSION

Results of the multiple regression analysis yielded approximately 2,000 equations, with coefficients of determination (R^2) ranging from 0.29 to 0.99, and standard errors about the regression line ($S_{y \cdot x}$) ranging from 0.001 to 23.905 expressed as a percent (table 3). Number of observations (n) used to construct equations ranged from 3 to 89, with an average of approximately 55 observations. There is a regression equation for each species in each pathway for a habitat type phase. Table 4 shows some examples of regression equations. An interesting result of

Table 3—Summary statistics for FORSUM regression analysis. Statistics are stratified by habitat type phase (Arno and others 1985)

Summary statistic ²	Habitat type phase ¹						
	PSME/ PHMA, DRY	PSME/ PHMA, MOIST	PSME/ VAGL, XETE	ABLA/ XETE, VAGL	ABLA/ XETE, VASC	ABLA/ MEFE, WARM	ABLA/ MEFE, COLD
Number of pathways	9	6	8	8	9	6	8
Number of species	38	40	36	34	30	43	37
Number of equations	342	240	288	272	270	258	296
Average number observations (n)	23	16	36	33	22	22	18
Range of observations (n)							
Low	4	4	5	4	3	6	5
High	83	44	88	89	55	57	54
Average R^2	0.74	0.71	0.76	0.72	0.70	0.75	0.76
Range of R^2							
Low	0.42	0.31	0.36	0.35	0.32	0.34	0.29
High	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Average $S_{y \cdot x}$	4.667	4.628	3.747	4.463	3.851	3.828	3.737
Range of $S_{y \cdot x}$							
Low	0.010	0.001	0.001	0.011	0.223	0.003	0.001
High	23.095	20.041	17.773	20.098	21.077	19.880	20.110
Total number of regression equations: 1,966							

¹PSME = *Pseudotsuga menziesii* (Douglas-fir)
 ABLA = *Abies lasiocarpa* (subalpine fir)
 VAGL = *Vaccinium globulare* (blue huckleberry)
 VASC = *Vaccinium scoparium* (grouse whortleberry)
 MEFE = *Menziesia ferruginea*
 XETE = *Xerophyllum tenax* (beargrass).

² R^2 = coefficient of determination; $S_{y \cdot x}$ = standard error about the regression line. Note: units are in percent.

Table 4—Examples of regression equations used to predict successional plant cover in the model FORSUM

Habitat type phase	Pathway	Dependent or Y variable	Remainder of regression equation with the independent variables
PSME/PHMA, DRY	4	SYAL ¹	= 1.910 + 0.658(PRED) + 22.745(1/CC)
PSME/PHMA, MOIST	3	PHMA	= 2.002 + 0.970(PRED) + 0.023(AGE)
ABLA/MEFE, WARM	1	VAGL	= 3.256 - 0.031(SLP) + 0.023(AGE)

¹Variable definitions:

SYAL - Percent canopy cover of *Symphoricarpos albus* or snowberry.
 PHMA - Percent canopy cover of *Physocarpus malvaceus* or ninebark.
 VAGL - Percent canopy cover of *Vaccinium globulare* or huckleberry.
 PRED - Predisturbance cover (in percent) of the dependent or Y variable.
 CC - Percent canopy cover of all overstory tree species.
 AGE - Successional age of stand in years.
 SLP - Slope of stand in percent.

the regression analysis was the importance of predisturbance species cover for predicting postdisturbance cover. This is consistent with the theory of Egler (1954) and the findings of Lyon and Stickney (1976).

The FORSUM program is composed of 21 subroutines and a main driver. It has an interactive routine with error checking capability that makes it easy to enter data and use the model for predicting vegetation cover resulting from different treatments. The interactive routine was designed to accommodate two levels of expertise, one guiding inexperienced users through every step, and a second, streamlined version for quick data entry. A generalized flow chart showing the use of FORSUM is presented in figure 3. Once input values are entered, FORSUM keys the appropriate successional pathway from habitat type phase, treatment type, severity type, and vegetation coverage for the pretreatment community. The program then accesses the pertinent regression equations from external computer files and uses them to calculate posttreatment coverage predictions for each species. The user can choose to display (on the computer terminal) or print (to a line printer) graphs and tables of cover predictions (examples are shown in figs. 4 and 5). Also, the user may view three important statistics for the regression equation used to predict successional cover: coefficient of determination (R^2), number of observations (n), and standard deviation about regression (S_{y-x}).

Testing or "validation" results (table 5) showed that the model averaged 74 percent accuracy in predicting the correct cover class for all species. More importantly, the successional pathway was never misidentified. Tree species proved to be more difficult to model (65 percent accurate) than undergrowth species (82 percent accurate). This was probably due to the inherent variability involved when trees became established from seed rather than from vegetative sprouts. Predictions for clearcutting followed by broadcast burning or mechanical scarification were more accurate (79 percent) than predictions for wildfire or clearcutting with no site preparation (71 percent). Perhaps this is because broadcast burns and mechanical scarifications create more uniform conditions in the stand than wildfire or no site preparation. The model averaged 87 percent accuracy within (plus or minus) one cover class. This gain in accuracy was mostly in the smaller cover classes (cover class T and cover class 1), which could be combined for use in management planning.

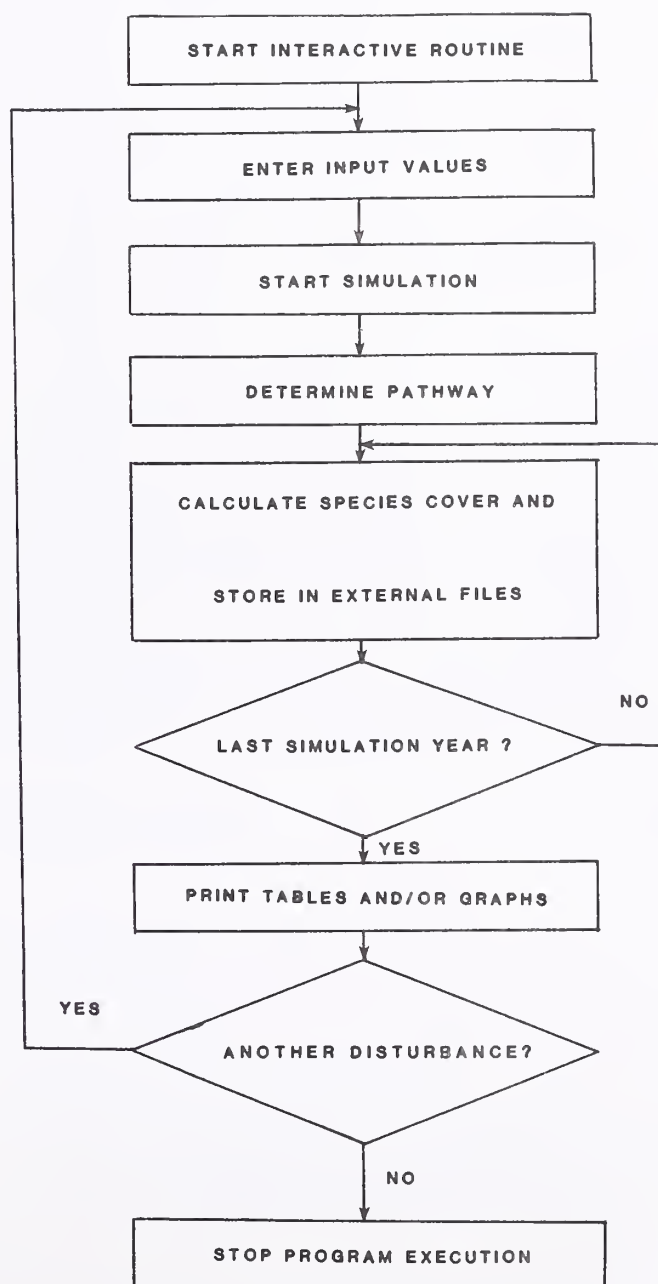


Figure 3—Flow chart of FORSUM succession model.

TITLE OF THE SIMULATION RUN: AN EXAMPLE RUN FOR TABULAR DISPLAY											
DESCRIPTION OF THE SIMULATION AREA: ELEVATION : 6200, FEET ASPECT : 270, DEGREES SLOPE : 27.5 (PERCENT)						TREATMENT TYPE : CLEAR CUT WITH BROADCAST BURN INTENSITY TYPE : MODERATE HABITAT TYPE PHASE : PSME/VAGL,XETE					
A DIAGRAM OF THE MODELED SUCCESSIONAL PATHWAY											
SHRUB-HERB	SAPLING	POLE			MATURE SERAL			CLIMAX			
CEVE	----> PICO-PSME/CEVE	----> PICO-PSME/VAGL-CARU			----> PSME-PICO/VAGL-CARU			----> PSME/VAGL-CARU			
PERCENT COVERAGE BY SPECIES FOR SPECIFIED AGES (YEARS)											
	PRE DIST	10	20	30	40	50	60	70	80		
TOTAL (%)	51 - 75	0	6 - 25	26 - 50	51 - 75	51 - 75	51 - 75	51 - 75	51 - 75	51 - 75	
INCHES)	17.0	0	2	4	5	5	6	7	7	7	
100 FT)	144.0	0	7	36	60	77	92	103	113	113	
< 4 IN.)	T	0	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	
TOTAL)	6 - 25	0	0	T - 5	6 - 25	6 - 25	6 - 25	26 - 50	26 - 50	26 - 50	
	T - 5	0	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	
	26 - 50	0	0	6 - 25	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	
INCHES)	T	0	0	0	0	0	0	0	0	0	
AL)	T	0	0	0	0	0	0	0	0	0	
	T - 5	0	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	
	T - 5	26 - 50	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	T - 5	
	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
	T	0	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	
	26 - 50	51 - 75	51 - 75	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	
	T	T - 5	T	0	0	0	0	0	0	0	
	26 - 50	6 - 25	6 - 25	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	26 - 50	
	T	6 - 25	T - 5	0	0	0	T - 5	T - 5	T - 5	T - 5	
	6 - 25	0	T - 5	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	
	T - 5	26 - 50	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	
	0	0	0	0	0	0	0	0	0	0	
	6 - 25	26 - 50	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	6 - 25	
	0	0	0	0	0	0	0	0	0	0	
	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	T - 5	
	T - 5	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
	T	T	T	T	T	T	T	T	T	T	
	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
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	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0							

Figure 4—Sample of a tabular output from FORSUM for a sample stand.

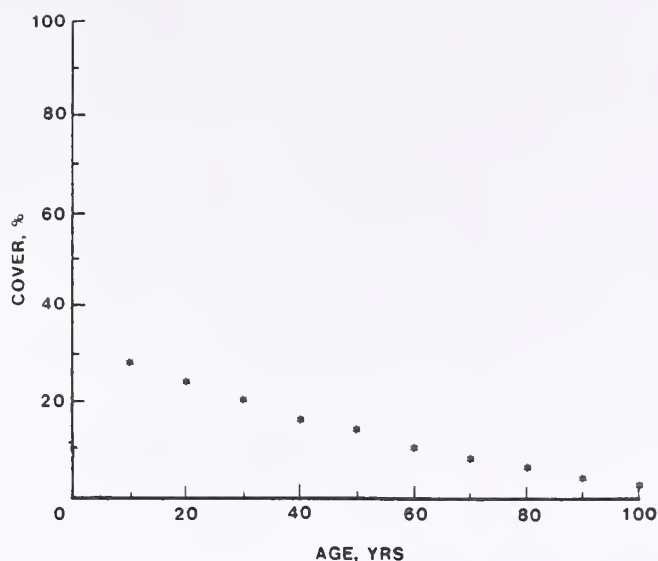


Figure 5—Sample of graphic output from FORSUM for shinyleaf ceanothus (*Ceanothus velutinus* = CEVE).

Table 5—The model validation summary. Accuracy of predictions is presented by habitat type phase. The first category of accuracy is computed by dividing the number of correct predictions by the total number of predictions. The second type of accuracy is computed by dividing the total number of predictions within a cover class of the observed value by the total number of predictions. The number in parentheses indicates number of stands sampled for the phase

Habitat type phase ¹	Overall accuracy of predictions	Accuracy within $\pm$ one cover class
----- Percent -----		
PSME/PHMA, DRY	78 (13)	85 (13)
PSME/PHMA, MOIST	73 (7)	84 (7)
ABLA/XETE, VAGL	71 (14)	86 (14)
ABLA/XETE, VASC	77 (10)	89 (10)
ABLA/MEFE, WARM	69 (12)	86 (12)
ABLA/MEFE, COLD	73 (8)	90 (8)
All Phases	74 (64)	87 (64)

¹The PSME/VAGL, XETE habitat type phase was not sampled.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

FORSUM seems to overpredict cover in younger age classes and underpredict in older age classes. This is probably a result of inadequate data representation for all age classes. Successional pathways with minimal plant diversity are more accurately modeled, suggesting that site factors play a more important role than competition in the less diverse habitat types. Regression equations are probably the weakest part of FORSUM. Results of validation indicate that data sets upon which the model was built do not fully represent the variation found in natural stands.

To mitigate this weakness, it is important that model results be used only in the study area (fig. 1). Lastly, the most sensitive routine in FORSUM is the keying of successional pathway. If the pathway is miskeyed, the wrong set of regression equations is chosen. Fortunately, validation has shown this to be a strong predictive part of the model.

FORSUM is currently available for use on Perkin-Elmer and Data General minicomputer systems and UNIVAC mainframe computers.² It was designed so additional habitat types can be added to the model with minimal modification. The user's manual (Keane 1985b) presents important information concerning programming considerations and execution procedures.

The main use of FORSUM is the prediction of the coverage of undergrowth and tree species as a result of different treatments. For instance, a forester might use the model to see if shrub and grass cover will be great enough to inhibit either natural or planted tree regeneration. A wildlife or range specialist might use it to assess alternative treatments for increasing certain forage species on a site. Vegetation response predictions could be compared to assess impacts of various treatments on watershed values or on visual quality. Nevertheless, it is important that the user understand that model predictions are only general trends in cover changes during succession.

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INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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